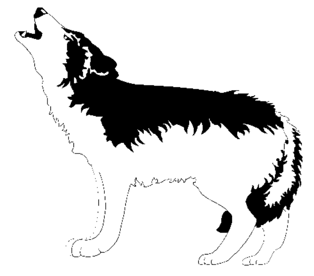
In My Opinion



Rigorous science: suggestions on how to raise the bar

David R. Anderson, Evan G. Cooch, R. J. Gutiérrez, Charles J. Krebs, Mark S. Lindberg, Kenneth H. Pollock, Christine A. Ribic, and Tanya M. Shenk

Abstract We offer suggestions for improving the validity of scientific inferences in wildlife ecology and management. These suggestions are offered under 7 categories as subjects of debate and refinement within our profession: university education, manuscript review and publication, professional meetings, in-service training, agency funding, review of field studies, and planning and assessment. We recommend consideration of the appointment of a Special Commissioner, working directly under The Wildlife Society (TWS) president, to oversee and coordinate various programs aimed at improving the rigor in our science and the educational opportunities of our membership. For such efforts to succeed, TWS membership must support attempts to better the science in our profession. We urge TWS members to become engaged in the process of improving the management of our natural resources by strengthening activities that will improve the quality of our science.

Key words education, in-service training, life-long learning, peer review, professional meetings, publication quality, research funding, scientific inference, science philosophy, university curricula

A goal of professionalism is always to try to do better. The broad field of wildlife ecology as an applied science produced many accomplishments during the twentieth century. However, as we look ahead, it seems clear that we must accept the challenge to do better—indeed, far better. Here we focus attention on the general subject of improving the quality of our science, for this will lead to better resource management.

An insightful entree into this important subject is Romesburg's (1991) paper, which we believe has been overlooked in comparison to his better-known and award-winning paper a decade earlier (Romesburg 1981). *The Journal of Wildlife Management* devoted a special section to "reliable knowledge" in 1991, 10 years after Romesburg's original paper. Now, 11 and 21 years later, we must face the fact that insufficient change has been made in the quality of our science. There is a high level of heterogeneity in our science products; some are quite exemplary, while too many are simply poor. Some people in our profession lack the education or experience to distinguish the good (e.g., valid, well done) from the poor (questionable validity, poorly conceived or executed). Romesburg would surely conclude that we have some better bungalows, but no Taj Mahals (Romesburg 1991:744) are on the drawing boards, much less funded. Wolff (2000) and White (2001) provide recent perspectives and urge more rigor in our work, and O'Connor (2000) and Swihart et al. (2002) offer a sense of urgency for change. We believe nearly everyone in our profession is aware of the problems and failures in some of our research programs. Perhaps our profession should do more to encourage and reward good work and show disdain and intolerance for poor work.

Our concern and comments are not meant to be an indictment of wildlife science relative to other field biology disciplines. Indeed, many of our comments are applicable to other areas of applied and theoretical ecology (Anderson et al. 2000). We too often address shallow research questions, and often our investigations lack controls or randomization or replication in cases where these are essential for strong inference. The use of poor experimental design, convenience sampling, inadequate sample size, confounding, index values, and similar issues frequently mar potentially important conclusions and fail to provide reliable information. Our university education and in-service training programs require substantial change; students, professors, and management and research biologists in the field see the shortcomings here. Publication quality needs reassessment, and our professional meetings may also need substantial change and reorganization. Peer-reviewed publications are the currency of science; we must do more to nurture high quality. Funding mechanisms and planning of new research are often inadequate and in need of substantial change. We need a roadmap to constructive changes within our profession that will result in improvements in the quality of our science, leading to valid inferences and better science-based management programs.

Our overall objective in this paper is to suggest ways to improve our science within seven broad areas of concern. We pose a number of questions and offer several suggestions that we hope will be viewed constructively. We invite others to debate these important subjects and further refine goals and programs that will lead to increased rigor in our profession and a strengthening of the basis for resource management. We encourage others to engage in honest debate over quality improvements in our science. We recognize that our paper will not find general agreement on all issues. Indeed, even we, as authors, do not agree entirely on each issue raised. Yet, we feel we need to push this debate farther to enhance the future of our profession. We must not let another decade go by without making substantial and measurable progress toward bettering our science and management programs.

University education in wildlife science

Substantive changes in our institutions of higher learning may be the most difficult to make because many problems are old and there are substantial fiscal, political, and social barriers to change. Ultimate causes of such inertia include limited department budgets, continual reallocation of university funds to emerging departments (e.g., molecular biology, computer science), and resource allocation based on quantity (e.g., large class size and high enrollments in the major) rather than quality. Many universities have rising teaching loads due to rising costs. The proximate result is often small faculties in wildlife departments whose members are sometimes burdened with excessive teaching and advising responsibilities. Teaching often includes several large service courses for nonmajors as well as required courses for majors. Teaching is particularly unrewarding in classes where many students are relatively unprepared. Faculty members are often expected to teach several large classes to capture university resources, leaving little time for graduate teaching and research. Excellent teaching seems to be relatively unrewarded in many research-oriented universities. Excessive undergraduate teaching loads lead to reduced quality of classes with attendant reduction in learning, understanding, and excitement. We will not try to suggest sweeping changes to alleviate these conditions (we are realists, but see Romesburg 1991); rather, we will focus on suggestions for improvement within the existing system.

Undergraduate education

We suggest a stronger emphasis on basic ecology, quantitative methods, computing skills, modeling, abstraction, and philosophy and history of science. These important subjects can promote scientific rigor and critical thinking in our students and should receive special emphasis. Courses within the wildlife major should perhaps place more focus on quantitative methods and modern ways to communicate critical thinking and results (see Burger and Leopold 2001, Cooper et al. 2001, Gould 2001, Johnson et al. 2001, Lopez 2001, Otis 2001, and Winterstein et al. 2001). We are not necessarily suggesting new courses to cover these subjects; rather, we suggest that these subjects be carefully integrated into virtually all existing science courses, both in wildlife departments and in elective courses in other departments. Burger and Leopold (2001), Winterstein et al. (2001), and Cooper et al. (2001) present examples of how quantitative subject matter was integrated into curricula. The challenge is to carry this integration out for other important topics as well, including natural history and ecology, which are so fundamental in our discipline (Wolff 2000). Porter and Baldassarre (2000) suggest we can increase our pace by actively building new criteria into our admission, teaching, certification, and hiring processes. This means that faculty and administrators must actively participate in college and university curriculum design. Generally, wildlife departments offer a Bachelor of Science, and this degree should have a very keen science focus.

TWS certification should allow more flexibility and diversity than is currently allowed. Perhaps there should be a higher premium on courses that help one think, reason, and solve problems, as opposed to so much memorization. The computerized information revolution has changed our learning environment; courses now need to place more emphasis on skills that computers lack (e.g., creativity, hypothesizing, reasoning, and clear thinking, but see Mjolsness and DeCaste 2001). Team-teaching might be underutilized in many academic programs. It is rare for professors in statistics and ecology to teach highly interactive classes at the interface between ecology and statistical science. We need innovative ways to foster interdisciplinary learning and research across departmental boundaries. Are graduates prepared to understand adaptive resource management methodologies (Williams et al. 2002)? Should not more be taught concerning conflict-resolution methods? The curriculum should not allow students to avoid the tough courses, although this practice has become common. Some university programs educate people primarily for entry-level positions (e.g., the B.S. degree with a heavy emphasis on field techniques) while other programs prepare them for higher-level professional positions (i.e., a focus on advanced courses and science methodology). Both approaches are necessary and important, but both should educate with a premium placed on creativity, innovation, critical thinking, and science. The larger issue concerns the basic ecological training students receive before they tackle application of principles to real-world problems. If students have only cursory understanding of ecology and science principles, how can we teach them applications unless the applications themselves are cursory? State and federal agencies hiring new recruits should recognize these important issues, as should academic faculty when selecting students for graduate programs.

One of our colleagues provided an analogy that is remarkable for its clarity, and we paraphrase his observations here. Approximately 100 freshman entered a mechanical engineering program at a large university, and 32 graduated from this program 45 years later. The majority of students either switched majors or dropped out for various reasons. Graduation in this program required meeting high standards; the faculty was not willing to compromise those standards. It is no secret that getting a degree in one of the various engineering fields is demanding. Much of engineering has a quantitative component, and if a student is unwilling or unable to become proficient in quantitative matters (and the associated computer methods), then the student does not receive a degree in that major. Wildlife biology may not require quite the same level of quantitative expertise as does engineering; however, everyday issues in various management programs see a wide variety of issues that are fundamentally quantitative (e.g., Leslie matrices to estimate rates of population change; adaptive resource management; a wide array of statistical methods; decision-theoretic approaches; resource-selection functions; risk-assessment methods; estimators of survival, extinction, and detection probabilities and their associated covariance matrices). Wildlife biology is highly empirical and is quantitative by its very nature. Yet, many universities grant degrees in wildlife biology to students who have essentially no such skills and, worse, see no value in quantitative thinking. In our opinion, these scenarios are simply wrong. Indeed, in our profession we certainly need a variety of other skills and knowledge (e.g., writing, public speaking, human dimensions, ethics, public policy, basic biology, and natural history) just as a mechanical engineering major must spend some time in the machine shop. However, the engineering student cannot get a degree with only machine-shop skills, whereas a wildlife biology major typically has little difficulty getting a degree with essentially no quantitative abilities beyond algebra and trigonometry. This scenario leaves the graduate unable to serve the profession well or assist in either advancing the science or assisting effectively with real-world management programs. This fact seems to be both common and fundamentally important. Too often we hear the statement, "I never had calculus, and it has never hurt me." Such statements deserve our professional condemnation.

Graduate education

Keppie (1990) provides an excellent template for graduate student research. Now, 12 years later, we must admit that his advice has commonly been ignored. He cites Chamberlin's (1890) method of multiple working hypotheses as a fundamental reference point that enhances creativity and innovation while being an effective science strategy. Keppie (1990) suggests that we often ask poor research questions. We must ask why our profession seems so locked to the status quo in the face of logical arguments about the need to change.

University graduate programs must do more to keep abreast of important new issues, teach exciting new concepts, pose deeper questions, and foster a skeptical attitude among advanced students. Too few graduate courses seem to be offered in most wildlife departments that have a graduate program. Thus, students should be encouraged to take advanced courses from other departments in fundamental subjects such as ecosystem dynamics, community ecology, decision theory, population genetics, and social sciences. Students should be encouraged to take advanced courses (and receive credit) from more than one university. This system would allow individual students to tap expertise at multiple universities. Much more educational experience is needed on fundamental issues such as discovery, creativity, causation, sampling, experimentation, confounding, randomization, inductive and deductive inference, hypothesis formulation, and modeling. However, all graduate courses should be a platform for the reinforcement of important, fundamental science principles and strengthening their ability to conceptualize.

The idea of integration of important principles should be carried over into all graduate curricula. We need to look critically at how topics we deem important are taught by other departments. For example, service courses in statistics departments for nonmajors often cover methods developed in the 1920s and 1930s (e.g., fixed-effects ANOVA and various null hypothesis testing procedures; see Duckworth and Stephenson 2002). The many advances in statistical science over the past 50 years often are relegated to majors-only graduate courses (e.g., generalized linear models, generalized additive models, random-effects models, likelihood approaches, Bayesian methods, and the bootstrap). Yet these techniques are increasingly important in wildlife science (e.g., Williams et al. 2002). Therefore, wildlife departments should encourage appropriate changes and updating in course content in courses offered by other departments.

Academic faculty and agency research leaders sometimes fail to effectively promote a culture of high professional standards and quality science. Part of the problem here is that even faculty members can lose their technical edge; here effective post-tenure review and a proper Sabbatical become increasingly important.

Choosing excellent graduate students is critical for the future of our profession. We need to choose students (who want to have a research career) who are committed to the wildlife discipline, have academic backgrounds that include solid science courses, have outstanding records of scholarship, and are graduates from top schools. We believe that a national search for graduate students (Romesburg 1991) can only improve our choices of finding excellent and committed students. We do not wish to imply a formula that ignores important intangible assets, but we must ask whether we have routinely selected students with deliberation as to their high quality?

How do we demonstrate to our graduate students that they must strive for excellence? Graduate students often begin their field work without sampling or experimental design courses and without sound advice from experts in these subjects. Worse yet, others begin field work without a solid theoretical foundation to underlie their research. We propose that all students be required to write a meaningful research proposal prior to beginning their data collection. This proposal should be reviewed by the student's graduate committee, at the minimum, and the proposal should be revised in light of those comments and any pilot study conducted. Some departments require a seminar where the proposed study is presented to the department prior to the initiation of field work. If taken seriously, the graduate student starts to learn the importance of planning, design, review, and revision at an early stage.

We suggest that the use of graduate core curriculum and comprehensive examinations can be useful in raising and maintaining standards. A core curriculum is often useful because it allows the department to establish the basic level of science knowledge all graduates should have, regardless of their backgrounds. Comprehensive examinations (preferably written and oral) can be used as an opportunity to evaluate how students synthesize material and think creatively, qualities we need to encourage in developing both top scientists and managers.

Manuscript review and publication quality

Perhaps this is an area that is most easily changed because it lies almost totally within our profession and therefore our control. An overriding cause of problems in this area is the crushing "publish or perish" pressure on scientists, which results in a large number of manuscripts submitted to TWS and other publication outlets. Even with very good editors and associate editors, it is often difficult to obtain constructive, critical reviews within a timely period. Too often associate editors have served as postmen, passing poor reviews along to hapless authors. Specific changes in this system might rest largely on past editors, who have the institutional memory to make logical suggestions for improvement in our science literature. We recommend that TWS appoint a select, blue-ribbon panel to explore constructive and effective ways to improve the rigor in our journal publications. Such a panel could seek solutions to current problems as well as anticipate future challenges. We offer several suggestions that might lead to increased quality in our science publications.

Editors could lessen the frequency of papers sent to 2 reviewers having the same taxonomic specialty (e.g., avoid sending a paper to 2 reviewers who work on the same species). The quality of the review and the level of communication might be better if a paper were sent to one reviewer who works on the same or closely related species and to a good scientist working with another taxonomic group in an effort to evaluate the science rather than the species.

Considering the many recent advances in data analysis methods, perhaps many manuscripts would benefit substantially from review by a person knowledgeable in quantitative methods. The Biometrics Working Group within TWS might be able to play a role here, at least in an experimental situation. Reviews by quantitative scientists have been tried in the medical literature. Perhaps we should gain experience with this system, evaluate it, and let the results suggest the next step.

The process of peer review is complex, yet it is a critical component necessary to raise the standards of research and publication. The *Journal of the American Medical Association* has sponsored a series of international congresses whose purpose is to explore this subject (online at http:/www.ama-assn.org/public/peerhome.htm). People involved in the editorial process should avail themselves of the extensive research on peer review. Our field has usually kept reviewers anonymous, but other fields have used a double blind or totally transparent review system (in which both the author and reviewers are known to each other). We suggest evaluating these alternative systems. For example, place a random sample of manuscripts under careful control of a Special Editor who would oversee these experiments, make an evaluation, and suggest changes that might be implemented to improve quality.

Reviewing papers is a difficult task if taken seriously. Perhaps we need to explore ways to reward excellent reviewers. Such recognition need not be monetary. For example, feedback from authors might be sought, even from those whose papers were rejected, to understand how substantive the comments were. Editors could be polled as well; clearly, some additional thought on this subject would be useful. Perhaps reviewers should be asked to sign reviews, which might encourage fairer and more constructive review comments.

Perhaps a broader list of reviewers should be assembled; here is another area where past editors could have input. Reviewers themselves should be evaluated and those who are clearly poor could be placed on a list, preventing their being asked to review manuscripts as editors change. Perhaps reviewer evaluations should be better institutionalized and passed among editors.

The editor's cover letter to potential reviewers ought to encourage them to return the manuscript if they do not feel qualified to provide a competent review. Or perhaps the prospective reviewer is familiar with the animal or habitat that is the subject of the manuscript but does not understand the analysis of the data; such a reviewer should make it clear to the associate editor that the review is only partial and that a review of the data analysis must rest with another reviewer.

We suggest that thought be given to a reviewer checklist relating to issues of valid inference, modeled after the checklist now used for editorial matters. Clearly, there is no exact prescription for valid inference, but there are guidelines for assuring that inferences made are legitimate, given the methods used for data collection and analysis. This suggestion is likely to be controversial and lead to lost opportunity. Are we spending too much effort on editorial form and standardization and too little time on substance?

Might there be advantages in categorizing papers published? The goals and value of studies vary, and these categories might aid in interpretation and application of the results. For example, causation should not be inferred from a natural history study. Categories such as natural history, observational studies, strict experiments, and data-less modeling might be useful to readers. A brief description of each category would be available to the reader, and these broad categories could comprise the formal sections of the journal. Finally, we even considered the use of "warning labels" that alert the reader concerning, for example, the lack of causal inference, the large unexplained variation in predictions, or the lack of rigor in the inductive inference from the sample to the larger population of interest. At the least, these issues should appear in the Methods or Discussion sections.

Considering the large number of manuscripts submitted, perhaps the editor or associate editor should often return manuscripts (without review) when the manuscript reports on work that is fundamentally flawed. Returning manuscripts without formal review might be a viable alternative if done with compassion and a good, objective explanation of the important limitations noticed. Submission of a manuscript to a TWS publication should not obligate the formal review process.

Professional meetings

We posit that our national meetings often demonstrate the substantial lack of scientific rigor that underlies our concern for the future of our profession. We characterize our concern with the following scenario: hundreds of abstracts are submitted long before the meeting, the acceptance rate is nearly 100%, papers are loosely partitioned into many sessions, session chairs are assigned post hoc, speakers are given 15 minutes to present their papers, and time is rarely left for meaningful discussion or debate following the presentation. We suggest that this common scenario is a poor use of people's time and can be improved substantially.

We suggest a substantial departure in the organization of the scientific papers for future national and international TWS meetings. Perhaps a Select Panel could be appointed and charged with developing guidelines for restructuring these meetings to enhance quality science while minimizing unintended impacts due to the changes. We provide several ideas here to promote thinking and discussion.

The number of papers presented would be roughly halved to allow fewer but longer papers to be presented. Abstracts submitted would be carefully reviewed and acceptance limited. Abstracts for work yet to be completed would not be accepted, unless perhaps as a poster. Three to 5 special symposia would be a highlight of the conference, and the planning and coordination of these might be expected to take 1–2 years, with high standards imposed. Here, the session chair would be expected to be very active during the entire process.

The main conference could include several plenary papers, possibly with formal discussants, dealing with issues that seem fundamental to our field (e.g., resource selection). Papers presented would be expected to have high science standards. Perhaps graduate students could be helpful in the review of abstracts for these sessions, as this would give them a forum to practice their skills in recognizing scientific rigor. Some speakers would have as few as 20 minutes, while others might have 50 minutes. A key feature here is to assure that time is left for discussion and debate. One day of the conference might be reserved for student papers, with an award system for best science (with less emphasis on merely presentation graphics). Controversial topics could be programmed as round-table or panel discussions to air opposing views.

Poster sessions should be an important feature of the annual conference. Posters could be highlighted in evening sessions and should be held in an excellent room with adequate space, good acoustics, and ample refreshments. Adequate time should be set aside to highlight these sessions and promote good interaction.

There are important reasons to attend professional meetings other than giving a paper. Many agencies require that an employee present a paper or poster in order to be reimbursed for trip expenses; this is simply short-sighted policy. It may be better to go to a meeting to listen and understand new science and management results than to present a 15-minute paper. If the annual meetings were creatively restructured, perhaps people could receive some type of in-service training credit for attending special symposia or workshops. It might often be helpful to ask a person who attended a professional meeting to give a seminar for others in the agency or university to discuss the meeting highlights and how these might be useful in agency or educational programs.

Based on the above suggestions for professional meetings, TWS officials and other groups might try such a restructuring, evaluate the outcomes from several different viewpoints (including graduate students), and suggest changes for future national meetings. In the end, we might learn that there needs to be diversity in the format of annual meetings. Still, meetings with hundreds of short, low-quality science papers, with no discussion, seem to be of limited value. Some of our better students recognize these problems, and we must respond with effective changes. We acknowledge the intangible values of these meetings (e.g., seeing colleagues, meeting new people, interacting with students, seeking partnerships and funding) and recognize them to be legitimate aspects of the annual meeting. However, unless the quality of science is high, the central part of the meeting is severely compromised. Few would argue the need to greatly improve the science and information exchange at our national and international meetings.

In-service training and life-long learning

Perhaps our greatest failure as a profession has been the near total lack of meaningful science education after people complete their formal academic degree programs. Academic faculty have a Sabbatical program that helps them stay current and excited; agency people often find it difficult to engage in meaningful life-long learning, usually due to budget constraints. Agencies should encourage such valuable training because funds invested in in-service training are well spent.

Little such training is offered by either agencies or universities. Our field is changing rapidly, and professionals must be given the opportunity to keep abreast of a large array of general technical advances, ranging from behavioral ecology to sampling and experimentation, analysis theory, computer software, philosophy, human dimensions, conflict resolution, and conservation genetics. Perhaps state and federal agencies, nongovernmental organizations, and universities should all begin to put a higher premium on in-service educational experiences that emphasize science issues. While we generally oppose mandatory regulations, science training could be included in performance standards, now used by a number of agencies.

Other professionals are required to successfully complete in-service training programs or lose their certification. Medical doctors, dentists, attorneys, many engineers, and other professionals are required to obtain necessary training throughout their careers. Imagine going to a medical doctor who is 20 years post-M.D. degree and learning that he has never had additional medical training. We believe TWS should move effectively to encourage major changes in our profession in terms of post-university education. Perhaps this could start with deliberate efforts to offer an array of top-quality 25-day workshops held on university campuses or in state or federal training centers ("If we offer it, they will come").

Good short courses are extremely valuable and enjoyable. We must encourage and expect this professional activity. University faculty should work with agency people to put on workshops and other in-service training experiences. Currently, there are relatively few courses or special sessions from which to choose. Science workshops often can precede or follow national meetings, saving on travel costs. Leadership is needed to plan and conduct quality training workshops as part of regional, national, and international TWS meetings.

Many of our graduates do not belong to even a single professional society, much less regularly read various journals. This situation is debilitating and surely reflects a substantive problem in the profession. Several years ago, a survey of United States Fish and Wildlife Service refuge managers found that slightly less than half belonged to The Wildlife Society. We suspect that other groups would not fare much better. Schmutz (2002) estimated that less than one-third of all wildlife biologists employed by the United States Fish and Wildlife Service are members of TWS or subscribe to any of its journals. A reviewer commented to us that TWS membership ought to be 20,000 instead of the 8,000–9,000 we regularly sustain. Why aren't all people in wildlife biology members of at least one professional society and active in its programs? Do such people see themselves as professionals? In-service training and life-long learning should begin with active membership in professional societies and professionals regularly reading (and perhaps contributing papers to) the relevant journals.

Agency funding

Agency funding (federal, state, provincial, or local) is the life blood of wildlife research. However, the mechanisms and processes for allocating funding are as varied as the agencies that provide the funding, though almost all agency funding requires a product (i.e., a "deliverable"). However, to elevate science quality, there must be greater communication and consistency in allocating funding within and among funding agencies. In addition, scientists must recognize that agencies have legal and public accountability requirements that may appear to conflict with the "best science." Therefore, we advocate better funding review mechanisms and communications between agencies and scientists both within and outside agencies.

Problems with allocation of funding may occur because of a lack of understanding of the nature of science and scientific processes by managers and administrators as well as the mandate an agency receives from its legislative controller. We can address this problem through education at all levels. For example, we should emphasize to our students the importance of defensible science, while scientists should relate their findings to the lay public, agency administrators, and legislators in such a way that good science is not only accepted but demanded. Changing political and social perceptions of the role of science, the objectives and capabilities of science, and the difference between good and poor science is a daunting task. It is the subject of "daily news" for many aspects of science. Yet, it is our responsibility as a profession to engage in this process. Ironically, within wildlife research, it has been the judicial system in recent years that has worked its way through a scientific minefield of claims and counterclaims about particular wildlife problems. Thus far, high-quality research has fared well (Marcot and Thomas 1997). The fact that high-quality research has influenced important judicial outcomes underscores the need for elevating the overall quality of all wildlife research.

While we offer no specific suggestions about the sociological issues that influence funding, we acknowledge their importance. However, we do provide some specific suggestions about how allocations of funding might proceed in order to achieve higher-quality research. There should be realistic expectations for a research program, given the level of funding or the product desired. This recognition is important for both the funding agency and the scientists proposing projects under the overall program. We suggest that agencies develop a system or structure that encourages critical review of general research programs and requests for funding proposals if they do not currently have one in place. Review of research programs would entail some level of true external review. It is our hope that rigorous review will lead to higher research quality by allowing agencies to direct their limited funds to answer the most important questions in the most effective manner.

Having a good program review structure should lead to discussion of coherent research strategies to meet both short-term and long-term research goals of an agency. Wildlife agencies and wildlife research in North America have existed in a culture of short-term goals when we need long-term vision to achieve higher-quality research that will help solve problems. A program review structure will also facilitate self-introspection at the level of the individual and group research projects and help educate those who are in charge of allocating funding. Some programs within the Environmental Protection Agency and the Minerals Management Service use Science Advisory Boards for program review; these programs might provide a template for adoption by wildlife agencies. The challenge here is to implement a meaningful review program without it becoming bureaucratic and needlessly tying up researchers in the process.

We encourage agencies to continue to fund research both internally and externally. In particular, we encourage agencies to invest more heavily in long-term projects. We believe past research performance of investigators must play an increased role in funding decisions. The National Science Foundation (NSF) puts a high premium on the past performance of investigators it funds, and this is a useful model for wildlife agencies funding research. Of course, consideration must be made for new people entering the profession, as they may often have less past performance to judge.

In large measure, NSF tends not to fund applied research, while state and federal agencies tend not to fund theoretical or conceptual research. These positions, in the extreme, are short-sighted, and more flexibility is needed to reach a better balance.

Agency research staffs can sometimes respond more quickly to specific agency needs and maintain great institutional memory of research and management issues. Thus, agencies should maintain their research capability. In addition, we believe it is critical for the health of the profession and the quality of our science that agencies consciously allocate funds to university or other extramural researchers, especially where graduate students are involved. Agencies will get the best scientists to work for them when they have direct involvement in training future researchers. Furthermore, in the end, unless top-quality people are routinely hired and allowed to grow in their profession, all is eventually somewhat futile.

Peer review of proposed field studies

Many wildlife and ecological field studies are seriously flawed, and this problem begs for constructive input from knowledgeable peers before field work begins. We encourage such review and would like to force more of it; however, it seems too easy to bypass effective peer review (e.g., "You review mine, I'll review yours") for those who do not take this matter seriously. Thus, we suggest that investigators rededicate themselves to better planning and design before data collection begins. Given a worthwhile objective or hypothesis, investigators must honestly seek expertise in sampling, experimental design, and field protocol; sophisticated analysis methods do not mitigate poor-quality data. As professionals, we cannot, for example, continue to perform experiments with no control, woefully inadequate sample size, substantial confounding factors, and no replication while hoping to infer causation (Morrison et al. 2001).

We must move beyond convenience sampling, index values, important assumptions that are simply not valid, and the poor thinking that underlies these issues (Anderson 2001). There is one primary reason to get the field work right: the credibility of our work. Such credibility can often be enhanced by the rejection of submitted manuscripts that are judged to be poor by the peer-review process and by rejection of proposed papers that have serious inadequacies by symposium organizers. If we raise the bar for science in our profession, we will see a point where competent data collection, study design, analysis, and proper inference become necessities.

As an ideal, there should be consistent, rigorous, and regular external review of both internally and externally generated research proposals. A final suggestion to improve field studies would be to consider the preparation of a multi-authored TWS book on sampling and design in wildlife field studies, patterned after the popular and effective series of the Society's wildlife techniques manuals published since 1960. Such a book might serve a wide variety of TWS members and could be updated as new methodologies become available (e.g., Latin square +1 and adaptive sampling).

Planning and assessment

We conclude by asking whether we can generally agree to accept the challenge to improve the basis for our science inferences. While enjoying our successes, can we admit to the myriad of inadequacies that surround us? Who will demonstrate leadership here? Can our conservative Society and its infrastructure take on sharply increased responsibility for a better focus on science issues? Currently, there is often little risk in making uninformed management decisions or doing sloppy science. Can we encourage more accountability in natural resources management? Can we hope that faculty retreats, advisory board meetings, agency staff meetings, and informal meetings among biologists will show concern for the validity of our science and move deliberately in directions that will improve quality? Will we see serious attempts to integrate some of these suggestions into existing programs? Can we expect a higher degree of professionalism in our activities? Will other professionals suggest additional improvements or help refine the ones we offer here? How will the effectiveness of these changes be judged and assessed? Will we let another decade go by without meaningful improvements necessary to move our profession closer to the cutting edge?

Is TWS making full use of online discussion groups and other features of the Internet? E-sessions on issues such as wildlife education, professionalism, and adaptive management might be fruitful. Perhaps students would benefit from their own discussion groups. Online discussion groups seem relatively unexplored within our profession.

Finally, we recommend consideration of the appointment of a Special Commissioner, working directly under the TWS president, to oversee and coordinate various programs aimed at improving the rigor in our science and the educational opportunities of our membership. This key position might help bring an emphasis to this critically important subject. For such efforts to succeed, the TWS membership must support attempts to better the science in our profession and enter into a period of rapid change.

Acknowledgments. We thank G. Baldassarre, J. Ringelman, and an anonymous reviewer for their thoughtful comments, both positive and negative, on an early version of this paper. In particular, we appreciate the insights offered by J. Nichols, several of whose ideas have been incorporated here.

Literature cited

ANDERSON, D. R., K. P. BURNHAM, AND W. L. THOMPSON. 2000. Null hypothesis testing: problems, prevalence, and an alternative. Journal of Wildlife Management 64: 912–923.

ANDERSON, D. R. 2001. The need to get the basics right in wildlife field studies. Wildlife Society Bulletin 29: 1294–1297.

BURGER, L. W., AND B. D. LEOPOLD. 2001. Integrating mathematics and statistics into undergraduate wildlife programs. Wildlife Society Bulletin 29: 1024–1030.

CHAMBERLIN, T. C. 1890. The method of multiple working hypotheses. Science 15: 93.

COOPER, R. J., M. J. CONROY, AND J. P. CARROLL. 2001. Wildlife biometrics training at the University of Georgia: adding quantitative emphasis to a wildlife management program. Wildlife Society Bulletin 29: 1049–1054.

DUCKWORTH, W. M., AND W. R. STEPHENSON. 2002. Beyond traditional statistical methods. The American Statistician 56: 230–233.

GOULD, W. 2001. Importance of biometrics education to natural resource professionals. Wildlife Society Bulletin 29: 1022–1023.

JOHNSON, D. H., T. L. SHAFFER, AND W. E. NEWTON. 2001. Statistics for wildlifers: how much and what kind? Wildlife Society Bulletin 29: 1055–1060.

KEPPIE, D. M. 1990. To improve graduate student research in wildlife education. Wildlife Society Bulletin 18: 453–458.

LOPEZ, R. R. 2001. Rigor in wildlife education: where the rubber hits the road. Wildlife Society Bulletin 29: 1038–1042.

MARCOT, B. G., AND J. W. THOMAS. 1997. Of spotted owls: old growth, and new policies: a history since the Interagency Scientific Committee Report. United States Forest Service, General Technical Report PNW-GTR-408.

MJOLSNESS, E., AND D. DECASTE. 2001. Machine learning for science: state of the art and future prospects. Science 293: 2051–2055.

MORRISON, M. L., W. M. BLOCK, M. D. STRICKLAND, AND W. L. KENDALL. 2001. Wildlife study design. Springer-Verlag, New York, New York, USA.

O'CONNOR, R. J. 2000. Why ecology lags behind biology. The Scientist 14: 35.

OTIS, D. L. 2001. Quantitative training of wildlife graduate students. Wildlife Society Bulletin 29: 1043–1048.

PORTER, W. F., AND G. A. BALDASSARRE. 2000. Future directions for the graduate curriculum in wildlife biology: building on our strengths. Wildlife Society Bulletin 28: 508–513.

ROMESBURG, H. C. 1981. Wildlife science: gaining reliable knowledge. Journal of Wildlife Management 45: 293–313.

ROMESBURG, H. C. 1991. On improving natural resources and environmental sciences. Journal of Wildlife Management 55: 744–756.

SCHMUTZ, J. A. 2002. Educational background and professional participation by federal wildlife biologists: implications for science, management, and The Wildlife Society. Wildlife Society Bulletin 30: 594–598.

SWIHART, R. K., J. B. DUNNING, JR., AND P. M. WASER. 2002. Gray matters in ecology: dynamics of pattern, process, and scientific progress. Bulletin of the Ecological Society of America 83: 149–155.

WHITE, G. C. 2001. Why take calculus? Rigor in wildlife management. Wildlife Society Bulletin 29: 380–386.

WILLIAMS, B. K., J. D. NICHOLS, AND M. J. CONROY. 2002. Analysis and management of animal populations: modeling, estimation, and decision making. Academic Press, San Diego, California, USA.

WINTERSTEIN, S. R., H. CAMPA III, K. F. MILLENBAH, AND T. G. COON. 2001. Infusing quantification into a fisheries and wildlife undergraduate curriculum: the Michigan State University model. Wildlife Society Bulletin 29: 1031–1037.

WOLFF, J. O. 2000. Reassessing research approaches in the wildlife sciences. Wildlife Society Bulletin 28: 744–750.

Address for David R. Anderson: Colorado Cooperative Fish and Wildlife Research Unit, Room 201 Wagar Building, Colorado State University, Fort Collins, CO 80523, USA; e-mail: anderson@cnr.colostate.edu. Address for Evan G. Cooch: Department of Natural Resources, 206B Fernow Hall, Cornell University, Ithaca, NY 14853, USA. Address for R. J. Gutiérrez: Department of Fisheries, Wildlife and Conservation Biology, 1980 Folwell Avenue, University of Minnesota, St. Paul, MN 55108, USA. Address for Charles J. Krebs: Department of Zoology, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada. Address for Mark S. Lindberg: Department of Biology and Wildlife and Institute of Arctic Biology, University of Alaska, Fairbanks, AK 99775, USA. Address for Kenneth H. Pollock: Box 8203, Departments of Statistics and Zoology, North Carolina State University, Raleigh, NC 27695, USA. Address for Christine A. Ribic: U.S. Geological Survey, Wisconsin Cooperative Wildlife Research Unit, Department of Wildlife Ecology, 226 Russell Labs, 1630 Linden Drive, University of Wisconsin, Madison, WI 53706-1598, USA. Address for Tanya M. Shenk: Colorado Division of Wildlife, 317 West Prospect Street, Fort Collins, CO, 80526-2097, USA.